KA-TP-7-1995
hep-ph/9508355
August 1995

EFFECTS OF R PARITY BREAKING IN THE HIGGS SECTOR

J. ROSIEK

Institut für Theoretische Physik, Universität Karlsruhe

We discuss possible manifestations of R parity breaking in the Higgs sector. We illustrate this with three examples: high-energy mono-photon production at LEP, calculation of limits on associated production of invisibly decaying Higgs bosons and discussion of non-standard scalar decays in the MSSM with broken R parity.

1 Introduction

In analysing the supersymmetric theories one usually assumes the conservation of a discrete symmetry, called R parity[1], distinguishing matter fields from their superpartners. The R parity violation could lead to phenomenologically interesting effects, such as mixing of gauginos with leptons[2] and Higgs bosons with sleptons[3,4] (and hence breaking of the lepton number), non-zero neutrino masses[5,4] and their decays[6], Z^0 decays to single charginos or neutralinos[7], existence of a massless Goldstone boson called majoron[8] and many others. In contrast to the R parity breaking in the fermion sector, its consequences in the scalar sector are relatively less explored. We present three examples of possible manifestations of R-parity breaking in the Higgs sector: high-energy mono-photon production at LEP[9], associated production of invisibly decaying Higgs bosons[10] and novel scalar decays in the MSSM with broken R parity[11].

2 Single Photon Decays of the Z^0 and SUSY with Broken R-Parity

Recently the OPAL collaboration has published a high statistics single photon spectrum that shows some excess of high energy photons above the expectations from g the initial state radiation (ISR)[12]. This excess could be explained in a class of SUSY models with spontaneous violation of R parity, which pre-

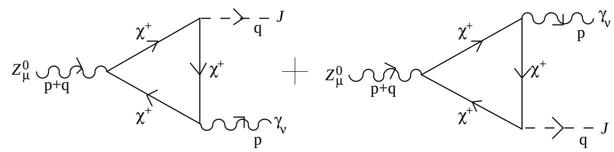

Figure 1: Diagrams contributing to the monochromatic single photon emission $Z^0 \to \gamma J$

dict the existence of new Z^0 decay modes involving single ($Z^0 \to J\gamma$) or double ($Z^0 \to JJ\gamma$) invisible massless majoron emission.

Single majoron emission would produce monochromatic photons emitted with energy $\frac{M_Z}{2}$. In order to estimate the attainable values of $\mathrm{Br}(Z^0 \to J\gamma)$ we adopt as a model for the spontaneous R parity violation the one proposed in[13]. Diagrams contributing at the 1-loop level to the process $Z^0 \to J\gamma$ are shown in Fig. 1. We obtained the explicit expression for $\mathrm{Br}(Z^0 \to \gamma J)$ by calculation of the 3-point Green functions of Fig. 1. We have varied model parameters, rejecting points violating constraints imposed by existing laboratory observations, cosmology and astrophysics. We have found that the branching ratio for the 2-body Z^0 decay to a single photon + missing momentum in the considered model can reach 10^{-5}, being within the sensitivity of LEP[9].

Double emission process $Z^0 \to JJ\gamma$ would give rise to a continuous photon spectrum.[a] Imposing gauge and CP invariance and Bose symmetry, one can express the on-shell amplitude in terms of a single form-factor V_0:

$$A(Z^0 \to JJ\gamma) = V_0[p^\mu(q_1+q_2)^\nu - p(q_1+q_2)g^{\mu\nu}]\epsilon_\mu(p+q_1+q_2)\epsilon_\nu(p) \qquad (1)$$

As the simplest illustration we derive the γ-spectrum following from eq. (1) in the approximation of constant V_0. We obtain

$$\frac{d\Gamma}{dE_\gamma} = \frac{|V_0|^2 M_Z}{96\pi^3}E_\gamma^3 \qquad\qquad 0 \le E_\gamma \le \frac{M_Z}{2} \qquad (2)$$

The details of the shape of the γ spectrum depend upon the specific model and SUSY parameters choice, but its general characteristic is determined by kinematics and is different from the SM process $Z^0 \to \nu\bar{\nu}\gamma$. Superimposed

[a]We do not consider here other possible mechanisms, like LSP pair production followed by the radiative decay of one of them $\chi^0 \to \gamma\nu$ and the invisible decay of the other $\chi^0 \to J\nu$.

upon the continuous spectrum we have, in addition, a spike at its endpoint, corresponding to the emission of the monochromatic γ in the $Z^0 \to \gamma J$ decay.

3 Limits on Associated Production of Invisibly Decaying Higgs Bosons from Z^0 Decays

In a class of models with a spontaneously broken global symmetry the CP-even Higgs boson(s) are expected to have sizeable invisible decay modes to the majorons[14]. This decay could contribute to the signal looked for at LEP – two acoplanar jets + missing momentum. The existing analyses of the invisible Higgs search have concentrated on a minimally extended SM Higgs sector with the addition of a Higgs singlet and hence on the Bjorken process[15]. We extend this analysis to include the model containing two Higgs doublets and a singlet (carrying lepton number)[13] and the associated production of the CP-even and CP-odd Higgs bosons[10]. For the illustration, we display the constraints obtained for the published ALEPH data sample[16] based on a statistics of 1.23×10^6 hadronic Z^0 events.

After spontaneous $SU(2) \times U(1) \times U(1)_L$ breaking, the Higgs sector of the considered model contains 3 massive CP-even scalars H_i, a massive CP-odd scalar A and the massless majoron J. We assume that at LEP only the lightest CP-even scalar $H_1 \equiv H$ can be produced. The relevant couplings are:

$$\mathcal{L}_{HZZ} = (\sqrt{2}G_F)^{1/2} M_Z^2 \, \epsilon_B \, Z_\mu Z^\mu H \quad (3)$$

$$\mathcal{L}_{HAZ} = -\frac{e}{\sin\theta_W \cos\theta_W} \, \epsilon_A \, Z_\mu H \overleftrightarrow{\partial^\mu} A. \quad (4)$$

where $\epsilon_A^2, \epsilon_B^2 \leq 1$. The main H decay modes are $b\bar{b}$, JJ and AA (if $m_H > 2m_A$). HJJ coupling strength is unconstrained and can be effectively parameterized by $B = \mathrm{Br}(H \to JJ)$, $0 \leq B \leq 1$.[b] The decay $A \to JJJ$ does not exist since the (CP-allowed) couplings AJ^3 or AHJ vanish at the tree level in our model. Since A can decay only visibly ($B_A = \mathrm{Br}(A \to b\bar{b}) \approx 90\%$ for $m_A \geq 20$ GeV),

[b] The parameterization of the expected number of the invisible Higgs boson events in terms of m_H, m_A, ϵ_A, ϵ_B and B is quite general and not limited only to the model[13].

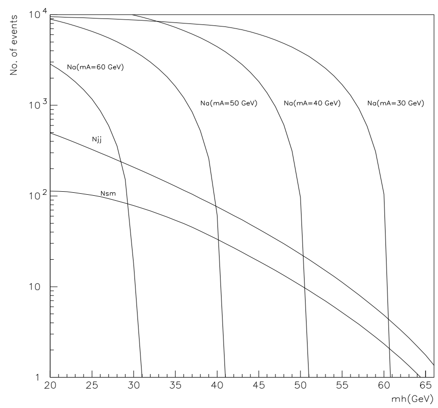

Figure 2: Numbers of expected dijet + missing momentum events after imposing ALEPH cuts.

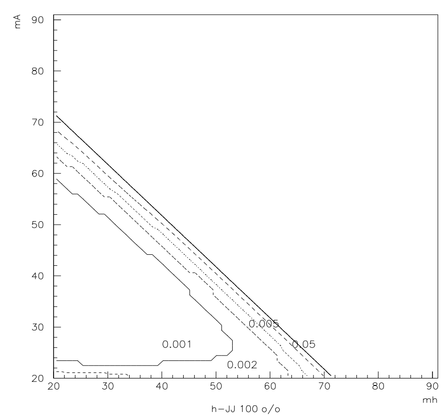

Figure 3: Limits on ϵ_A^2 in the m_A-m_H plane based on $e^+e^- \to HA \to JJb\bar{b}$ channel. We have assumed Br($H \to JJ$) = 100%.

one expects dijets + missing momentum as a signal of the Higgs production. This signal arises from three processes: 1) $Z^{0\star} \to \nu\overline{\nu}$, $H \to b\bar{b}$, 2) $Z^{0\star} \to q\overline{q}$, $H \to JJ$ and 3) $H \to JJ$, $A \to b\bar{b}$. For each process one has a sizeable missing momentum which is aligned neither along the beam nor along the jets. For the SM background missing momentum arises from i) jet fluctuation (including escaping ν from b, c and τ jets) in which case it is aligned along the jets, and ii) ISR or $e^+e^- \to (e^+e^-)\gamma\gamma$ process in which case it is aligned along the beam direction. This enables one to eliminate the SM background by a combination of kinematic cuts[17]. We denote the number of expected signal events for the processes 1)-3), after the cuts, by N_{SM}, N_{JJ} and N_A respectively, assuming no suppression due to the mixing angles or branching fractions in each case. The expected number of signal events, after incorporating these effects, is given by

$$N_{2j} = \epsilon_B^2 \left[BN_J + (1 - B)N_{SM} \right] + \epsilon_A^2 B_A B N_A \tag{5}$$

As can be seen in Fig. 2, $N_A \gg N_{SM}, N_{JJ}$, implying that, if not suppressed kinematically or by mixing angles, associated production gives the strong limits on ϵ_A^2 (see Fig. 3, where we have assumed fully invisible H decay). The limit on

ϵ_B^2 is given by the Bjorken process and is the same as obtained in[15]. A decay mode independent limits on ϵ_A^2, ϵ_B^2 can be obtained by varying B from 0 to 1 and combining the data on dijet + missing momentum with those from 4 and 6 b-jet searches. The overall limit is dominated by visible channels, which give weaker constraints on ϵ_A^2, ϵ_B^2 then those obtained for the invisible H decay.

4 Novel Scalar Boson Decays in SUSY with Broken R-Parity

The standard MSSM R parity conserving superpotential can be generalized by adding the following R parity (and lepton number) violating terms:

$$W_R = \epsilon_{ab}\left[\lambda_{ijk}\hat{L}_i^a\hat{L}_j^b\hat{E}_k^C + \lambda'_{ijk}\hat{L}_i^a\hat{Q}_j^b\hat{D}_k^C + \epsilon_i\hat{L}_i^a\hat{H}_2^b\right] \tag{6}$$

We focus on the effect of the last term in eq. (6), assuming in addition $\epsilon_{1,2} \approx 0$. The remaining $\epsilon_3\hat{L}_3\hat{H}_2$ term induces a non-zero VEV for the tau sneutrino: $\langle\tilde{\nu_\tau}\rangle \equiv \frac{v_3}{\sqrt{2}}$ and leads to mixing of gauginos with leptons, Higgs scalars with the tau sneutrino and hence to the R parity violating Higgs bosons decay modes.

All the elements of the various mixing matrices can be expressed in terms of six independent parameters which we choose as $\tan\beta = \frac{v_2}{\sqrt{v_1^2+v_3^2}}$, μ, ϵ_3, m_A^2, the gaugino and soft sneutrino mass parameters M_2 and m_{L_3}. We have taken into account the following constraints on the model parameters:

1) The major constraint on ϵ_3 and hence on R parity violating mixings comes from bound on ν_τ mass[18], induced by the non-zero ϵ_3: $m_{\nu_\tau} \leq 30$ MeV[c].

2) Decay widths $\Gamma(Z^0 \to \chi^0\chi^0, \chi^+\chi^-)$ should obey the LEP restrictions.

The decay $h \to \chi^0\nu_\tau$ occurs either through the sneutrino component of h,

$$h = a_{31}(\tilde{\nu}_\tau)_R + a_{21}(\phi_2)_R + a_{11}(\phi_1)_R \tag{7}$$

or through ν_τ admixture in the LSP in the $h\chi\chi$ vertex. The mixing a_{31} appearing in eq. (7) is of the order of $\mathcal{O}\left(\frac{\mu\epsilon_3}{m_h^2-m_{\tilde{\nu}_\tau}^2}\right)$ and become large if the *sneutrino* mass is close to the mass of the relevant *Higgs* boson. The relative importance of the SUSY decay mode $h \to \chi^0\nu_\tau$ follows from the ratio:

[c]see comments in[11] on possible cosmological constraints.

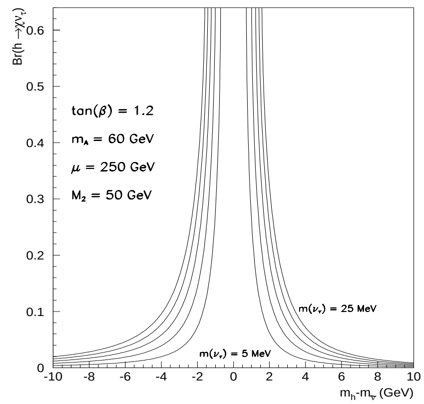

Figure 4: $\mathrm{Br}(h \to \chi^0\nu_\tau)$ as a function of the difference of the physical h and $\tilde{\nu}_\tau$ masses. The ν_τ mass labels the different curves.

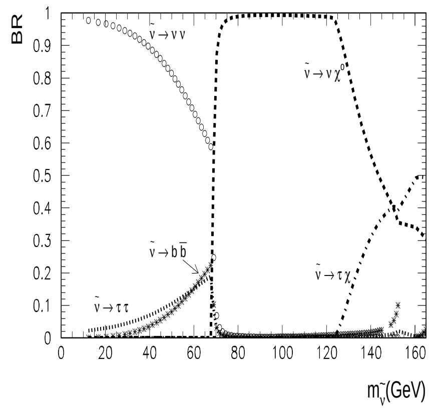

Figure 5: Branching ratios for $\tilde{\nu}_\tau$ decays as a function of its mass for $\tan\beta$=10,M_2=70 GeV,μ=200 GeV,ϵ_3=1 GeV,m_A=250 GeV.

$$R_0 = \frac{\Gamma(h \to \chi^0\nu_\tau)}{\Gamma(h \to b\overline{b})} \approx \frac{\tan^2\theta_W}{2}\frac{M_W^2}{m_b^2}\frac{(1-m_\chi^2/M_H^2)^2}{(1-4m_b^2/M_H^2)^{3/2}}\frac{a_{31}^2}{a_{11}^2}\cos^2\beta|\xi|^2 \tag{8}$$

where ξ denotes the appropriate gaugino-LSP mixing element. R_0 and also $R_+ = \frac{\Gamma(h\to\chi^\pm\tau^\mp)}{\Gamma(h\to b\overline{b})}$ can be estimated to be of the order of $\mathcal{O}\left(\frac{\epsilon_3^2}{m_b^2}\right) \times \frac{\mu^2}{(m_h - m_{\tilde{\nu}_\tau})^2}$ In Fig. 4 we display the branching ratios for h decays to LSP + ν_τ as a function of the h-$\tilde{\nu}_\tau$ mass difference, for a suitable choice of SUSY parameters. Clearly, for relatively small h-$\tilde{\nu}_\tau$ mass differences of a few GeV, the supersymmetric channel can dominate over the SM ones (similarly for $A \to \chi^0\nu_\tau, \chi^\pm\tau^\mp$ decays). Conversely, $\tilde{\nu}_\tau$ may decay into R parity violating SM channels such as $b\overline{b}$, $\tau^+\tau^-$ or the invisible mode $\nu\overline{\nu}$. These decays are dominant when the phase space for the R parity conserving channels such as $\chi\nu$ is closed (see Fig. 5 where $m_{LSP} \approx 65$ GeV) and may be non-negligible even above the LSP threshold if $m_h \approx m_{\tilde{\nu}_\tau}$, leading to a resonant enhancement of $b\overline{b}, \tau^+\tau^-$ modes (see small rise of $\mathrm{Br}(\tilde{\nu}_\tau \to b\overline{b})$ in Fig. 5 for $m_{\tilde{\nu}_\tau} \approx m_h = 155$ GeV). Finally, the R parity breaking terms lead to the unstable LSP, which would decay inside the detector if $\epsilon_3 \sim$ few GeV. Folding the R parity violating Higgs boson decays to the LSP with the standard decays of Z^0 one gets the signatures in e^+e^- collisions which do not occur in the SM, such as τe or $\tau\mu$ pairs + missing momentum[11].

Acknowledgements

This work was supported in part by postdoctoral fellowship of the Spanish MEC and by Alexander von Humboldt Stiftung.

References

1. S.Weinberg, *Phys. Rev.* **D26** (1982) 533; N.Sakai, T.Yanagida, *Nucl. Phys.* **B197** (1982) 533; for a review see J.W.F.Valle, *Nucl. Phys. B (Proc. Suppl.)* **13** (1990) 520 and *ibid.* **13** (1990) 195
2. G.G.Ross, J.W.F. Valle, *Phys. Lett.* **B151** (1985) 375; J.Ellis et al, *Phys. Lett.* **B150** (1985) 142
3. D.Comelli et al, *Phys. Lett.* **B224** (1994) 397
4. A.S.Joshipura, M.Nowakowski, FTUV/94-42, hep-ph 9408224
5. L.Hall, M.Suzuki, *Nucl. Phys.* **B231** (1984) 419; I.Lee *Nucl. Phys.* **B246** (1984) 120; K.Enqvist et al, *Nucl. Phys.* **B373** (1992) 95
6. J.C.Romão, J.W.F.Valle *Nucl. Phys.* **B381** (1992) 87
7. P.Nogueira et al, *Phys. Lett.* **B251** (1990) 142; R.Barbieri,L.Hall, *Phys. Lett.* **B238** (1990) 86; M.C.Gonzalez-Garcia, J.W.F.Valle, *Nucl. Phys.* **B355** (1991) 330; D.E.Brahm et al, *Phys. Rev.* **D42** (1992) 1860
8. Y.Chikashige, R.Mohapatra, R.Peccei, *Phys. Rev. Lett.* **45** (1980) 1926; for a review see J.W.F.Valle, *Prog. Part. Nucl. Phys.* **26** (1991) 91
9. J.C.Romão, J.Rosiek, J.W.F.Valle, *Phys. Lett.* **B351** (1995) 497
10. F.de Campos et al, *Phys. Lett.* **B336** (1994) 446
11. F.de Campos et al, hep-ph 9502237, in print in *Nucl. Phys.* **B** (1995)
12. OPAL collaboration, *Zeit. für Physik* **C65** (1995) 47
13. A.Masiero, J.W.F.Valle, *Phys. Lett.* **B251** (1990) 273; J.C.Romão, C.A.Santos, J.W.F.Valle, *Phys. Lett.* **B288** (1992) 311
14. J.D.Bjorken, report SLAC-PUB-5673 (1991); R.E.Schrock, M.Suzuki, *Phys. Lett.* **10B** (1982) 250; L.F.Li, Y.Liu, L.Wolfenstein, *Phys. Lett.* **B159** (1985) 45; J.C.Romão et al, *Phys. Lett.* **B292** (1992) 329
15. A.Lopez-Fernandez et al, *Phys. Lett.* **B312** (1993) 240; O.Eboli et al, *Nucl. Phys.* **B421** (1994) 65; D.P.Roy et al, *Phys.Rev.* **D48** (1993) 4224
16. ALEPH Collaboration, *Phys. Lett.* **B313** (1993) 299; **B313** (1993) 312
17. ALEPH collaboration, *Phys. Rep.* **216** (1992) 253
18. Particle Data Group, *Phys. Rev.* **D50** (1994) 1173